THE EFFECT OF HYDROELECTRIC DAMS AND SEWAGE ON THE DISTRIBUTION OF STONEFLIES (PLECOPTERA) ALONG THE BOW RIVER

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ABSTRACT

Adult stoneflies (Plecoptera) were collected from 17 sites along 346 km of the Bow River. Of 59 species collected in the study area, 43 were relatively common. Although a few species were found throughout most of the study area, many had relatively narrow distribution limits. An ordination technique differentiated four species associations. One of these associations was in the subalpine and montane vegetation zones, one near the boreal zone, and two were in the grassland zone. Sewage effluent from small towns had little or no effect on distribution of stonefly species, but hydroelectric dams and sewage effluents from a large city reduced the species diversity and abundance of Plecoptera. Two species were apparently eliminated from over 150 km of river by dams and by sewage from the city of Calgary, while the distribution of some species was not reduced appreciably by these factors.

Des "mouches de pierres" adultes (Plecoptera) ont été collectionnées dans 17 localités réparties sur 346 km le long de la rivière Bow. Parmis 59 espèces collectionnées au cours de cette étude, 43 étaient relativement communes. Si quelques espèces furent trouvées dans la plus grande partie de la région étudiée, de nombreuses espèces présentent une distribution réduite. Quatre associations ont été identifiées a l'aide d'une technique d'ordination. Une de ces associations existaient dans la zone subalpine et dans la zone à vegetation montagneuse, une autre fût identifiée dans la zone boréale, et les deux autres dans la zone des prairies. Les effluents d'égouts des petites villes ont peu ou n'ont pas d'effet sur la distribution des espèces de Plécoptères; par contre les barrages hydroeléctriques ainsi que les effluents d'egouts des grandes citées influencent sensiblement la diversité et l'abondance des espèces. Les barrages et les eaux d'égouts de la ville de Calgary ont apparemment éliminé deux espèces sur 150 km le long de la rivière; ces facteurs ne semblent pourtant pas réduire de maniere évidente la distribution de certaines autres espèces.

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INTRODUCTION

Sequential changes in distribution of Plecoptera as well as other aquatic insects along rivers has been documented in Europe (Berthelémy 1966, Kamler 1967) and in North America (Dodds and Hisaw 1925, Donald and Anderson 1977, Knight and Gaufin 1966). The principal objective of this present study was to describe distribution and associations of Plecoptera along the Bow River, and to identify distributions that have been altered by human activity in the watershed. This river is controlled by four hydroelectric dams, and several small towns and a major city discharge sewage into the river.

For many North American aquatic insects, including Plecoptera, identification of immature stages cannot be made below generic level (Wiggins 1966, Hynes 1970, Cummins 1974). Because most adult stoneflies do not disperse far from the shoreline of rivers, we used quantitative collections of adult stoneflies to give an estimate of abundance and distribution of aquatic stages.

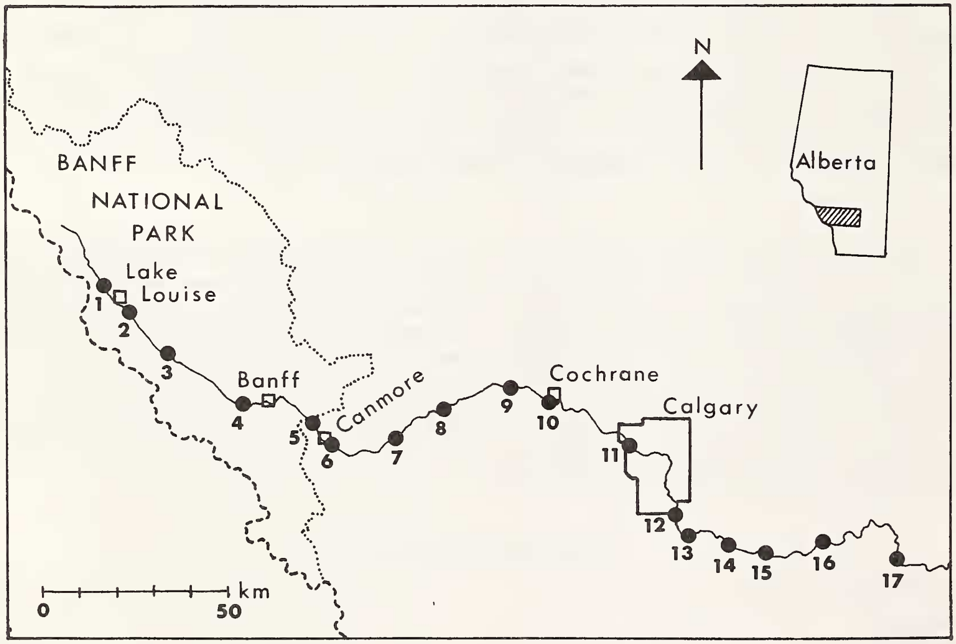

Figure 1. Map of study area showing the location of seventeen collecting sites on the Bow River.

METHODS

At the beginning and middle of each month, adult stoneflies were collected for 30 minutes along approximately 0.5 km of shoreline at each of 17 sites on the Bow River (Fig. 1). Collections were made in 1976 and 1977 from March to October. At one station, located within the city limits of Calgary, stoneflies were collected on a weekly basis, although only data compiled from the bimonthly samples were used in the main part of this paper. At each site vegetation was swept with an insect net, rocks along the shoreline were overturned and examined, and overhanging banks and bases of trees were checked for stoneflies. Because comparable sampling efforts were made at each site, these collections were presumed to be semi-quantitative relative to other sites. All specimens collected were preserved in the field in 70% ethanol. Identifications were made primarily with the aid of keys by Gaufin *et al.,* (1972). Scientific nomenclature follows that of Baumann *et al.,* (1977).

Mean specific conductance, and mean total coliform bacteria values were calculated from unpublished data provided by Environmental Protection Service, Alberta Environment and by Water Quality Branch, Environment Canada. Approximate locations of sites where measurements of water quality were taken can be determined from Fig. 2. Number of samples taken at each site ranged from 13 to 77 for specific conductance, and from 10 to 30 for total coliform bacteria counts. Daily discharge readings were taken at six sites on the Bow River, and at 12 sites on the larger tributaries of the Bow (Water Survey of Canada 1974). Number of years for which daily measurements were taken at these gauging stations ranged from three to 65.

Stonefly associations at the 17 sites along the Bow River were analysed with the Bray-Curtis polar ordination method (Whittaker 1973). The total number of each species collected at a site was determined. These abundance values were then converted to a percent of the total number of stoneflies collected at each site. The percent values were then used to determine similarity of the fauna at each site with the fauna of the other 16 sites. The most dissimilar sites became poles of the axes along which other sites are arranged.

THE STUDY AREA

The Bow River originates on the Continental Divide in Banff National Park and flows in a south-easterly direction through much of southern Alberta. The extreme upstream site (site 1) has a mean annual discharge of approximately 8.5 m∝/s and is about 35 km from the headwaters of the Bow River. The last site is 346 km downstream where mean annual discharge is about 109 m∝/s (Fig. 2). Over this 346 km distance the river passes through four vegetation zones (Rowe 1972): subalpine, montane, boreal, and grassland. In general, mean annual temperature increases downstream, while mean annual precipitation decreases. Maximum summer water temperatures at the furthest upstream and downstream sites are about 13°C and 23°C respectively. The Bow River is frozen over between December and March, but actual time of freeze-up and break-up at a given site depends on elevation, year, gradient, and distance from sewage outfalls or hydroelectirc dams.

Gradient of the Bow River in the study area is approximately 2.05 m/km and only few relatively short stretches have a gradient noticeably different from this (Fig. 3). At each

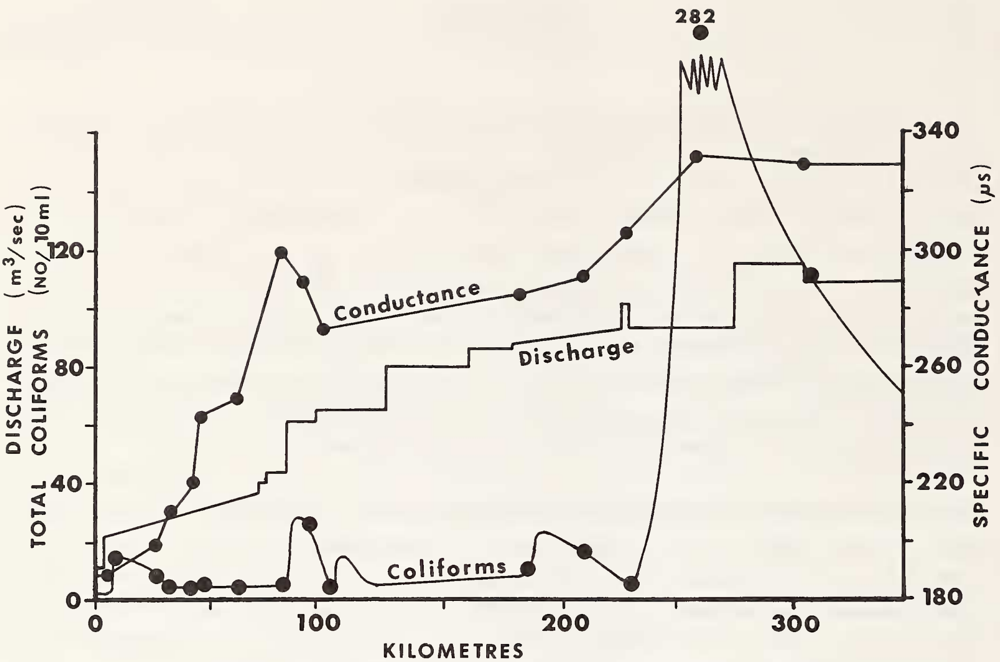

Figure 2. The specific conductance, mean annual discharge, and total coliform bacteria for the Bow River. A decrease in discharge shows location of weirs where water is taken for irrigation.

collecting site, areas of sand, gravel, and boulders were present.

The major dissolved constituents of the river water are bicarbonates of calcium and magnesium. Concentrations of common anions and cations increase in the downstream direction, similar to increase in specific conductance shown in Fig. 2. Oxygen concentrations were near saturation throughout the study area. The lowest oxygen concentration, 7.5 mg/l, was recorded downstream from Calgary.

Bow River water is used for town and city waterworks, generating electrical power, and irrigation purposes. Along the river are four towns and one city (Fig. 1). Lake Louise and Banff are resort towns, and their total population is usually much larger than number of permanent residents indicated in Fig. 3. Sewage discharged into the Bow River from towns and the city increases abundance of total coliform bacteria in the river (Fig. 2).

The four dams on the Bow River are used for generating electrical power (Fig. 3). The two upstream dams and the one furthest downstream have relatively constant daily discharge patterns, but the other dam has a variable daily discharge.

RESULTS

During this study, we collected a total of 4,372 specimens representing 59 species. Of these, 16 species were represented by a single specimen or were found at only one site. These 16 species were *Oemopteryx fosketti* (Ricker), *Zapada frigida* (Claassen), *Paraleuctra forcipata* (Frison), *Capnia gracilaria* Claassen, *Capnia petila* Jewett, *Alloperla serrata* Needham and

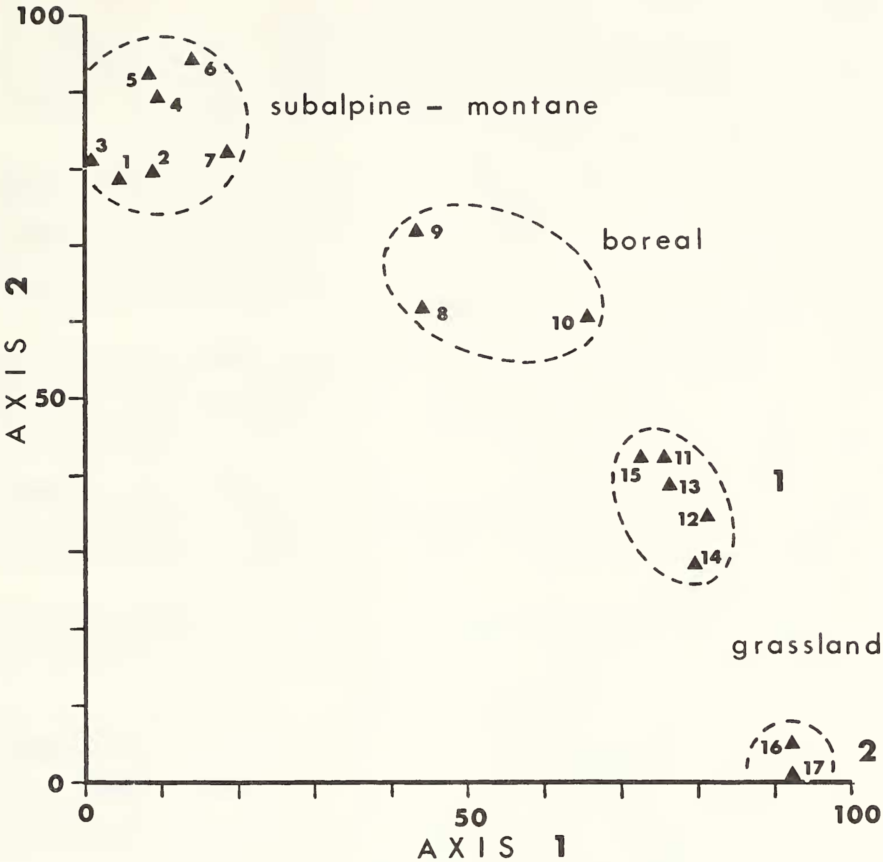

Figure 3. The gradient, number of species, and abundance of Plecoptera at seventeen sites on the Bow River. Dark triangles show location of hydroelectric dams. Vertical and horizontal bars show location and resident population of towns and city (see Fig. 1). Dotted lines indicate areas where species diversity and stonefly abundance would reach zero because of presence of reservoirs or sewage outfalls.

Claassen, *Sweltsa borealis* (Banks), *Malenka flexura* (Claassen), *Perlomyia utahensis* Needham and Claassen, *Isocapnia grandis* (Banks), *Isocapnia crinita* (Needham and Claassen), *Capnia coloradensis* Claassen, *Megarcys subtruncata* (Needham and Claassen), *Isoperla mormona* Banks, *Utaperla sopladora* Ricker, and *Calineuria californica* (Banks).

Distribution of 43 plecopteran species found along the Bow River is represented in Fig. 4. There was considerable variation in altitudinal distribution. Some species were restricted to either upstream or downstream sections, while a few species were found throughout much of the study area (e.g. the chloroperlids *Sweltsa coloradensis* (Banks) and *Alloperla severa* (Hagen).

Of 32 genera collected: 17 were represented by one species; 10 by two species; and five by three or more species. In general, ranges of congeneric species overlapped considerably (e.g. the perlodid species *Cultus tostonus* Ricker and *Cultus aestivalis* (Needham and Claassen) - Fig. 4), but there were some striking exceptions. For example, there was significant spatial separation between *Triznaka* species and between *Isoperla* species.

Nemourids and leuctrids were restricted to upstream areas (sites 1-9), while the other families of Plecoptera were represented throughout the study area (Fig. 4). Capniids were absent or reduced in abundance below hydroelectric dams (sites 8-11), especially the central dam (site 9 and 10, Fig. 4). Pteronarcids, capnids and perlids were absent or reduced in numbers downstream from Calgary (sites 12-14).

Figure 3 shows the total number of species collected at each site. Number of species decreased slightly downstream from both Banff and Canmore (sites 5 and 6). The fewest species were collected at site 9, 4.1 km below the central hydroelectric dam, and immediately downstream from Calgary (site 12). Approximately 30 km downstream from Calgary (site 15) number of species increased to levels similar to upstream sites, but then decreased sharply in an area that had no known environmental perturbations.

Stoneflies reached peak numbers downstream from Lake Louise (site 2), Banff (site 5), and near the upstream city limits of Calgary (site 11) (Fig. 3). The smallest number of specimens was collected below the central hydroelectric dam (site 9), and about 2 km below last sewage outfall from Calgary (site 12).

An arrangement of the 17 collection sites in relation to two axes by Bray-Curtis ordination is shown in Fig. 5. Four faunal associations were thus identified. Single associations occurred in the montane and subalpine vegetation zone, and in the general area of the boreal zone; two occurred in the grassland zone.

In order to obtain some information on reliability of our sampling method relative to number of species present at a site, and relative to the aquatic populations of Plecoptera found at a site, two comparisons were made. These are summarized below.

Fifteen plecopteran species were identified from site 11 where weekly samples were collected. If the normal bimonthly program had been carried out only 13 species would have been collected. The two species that were missed were represented by single specimens. Therefore, by doubling the sampling effort, the number of species found at this site was increased by 13%. Conversely, the bimonthly sampling program obtained about 87% of the species, and missed only those species that were very rare.

At two sites, one upstream, the other downstream from the town of Lake Louise (site 1 and 2, Fig. 1), larval stoneflies were collected by taking three kick samples at each site 15 times during 11 months of one year (Robinson and Smith Smith 1974). Identifications for this benthic study were made to subfamily, genus, or to species in a few cases. Using subfamily as the common level of identification, relative abundance of plecopteran larvae was compared to relative abundance of adults collected during the present study at these same sites (Table 1). This table shows that our method substantially underestimated relative abundance of Nemourinae, Isogeninae, and Acroneurinae at these stations, although our method obtained significantly more Capniinae. A comparison of taxa identified from these two studies indicated that the benthic study obtained 36% fewer taxa.

DISCUSSION

Comparison between adult and larval plecopteran collections from sites 1 and 2 on the Bow River indicated the two sampling methods obtained the same subfamilies but in different proportions (Table 1). Differences were probably related to vulnerability of species to either the

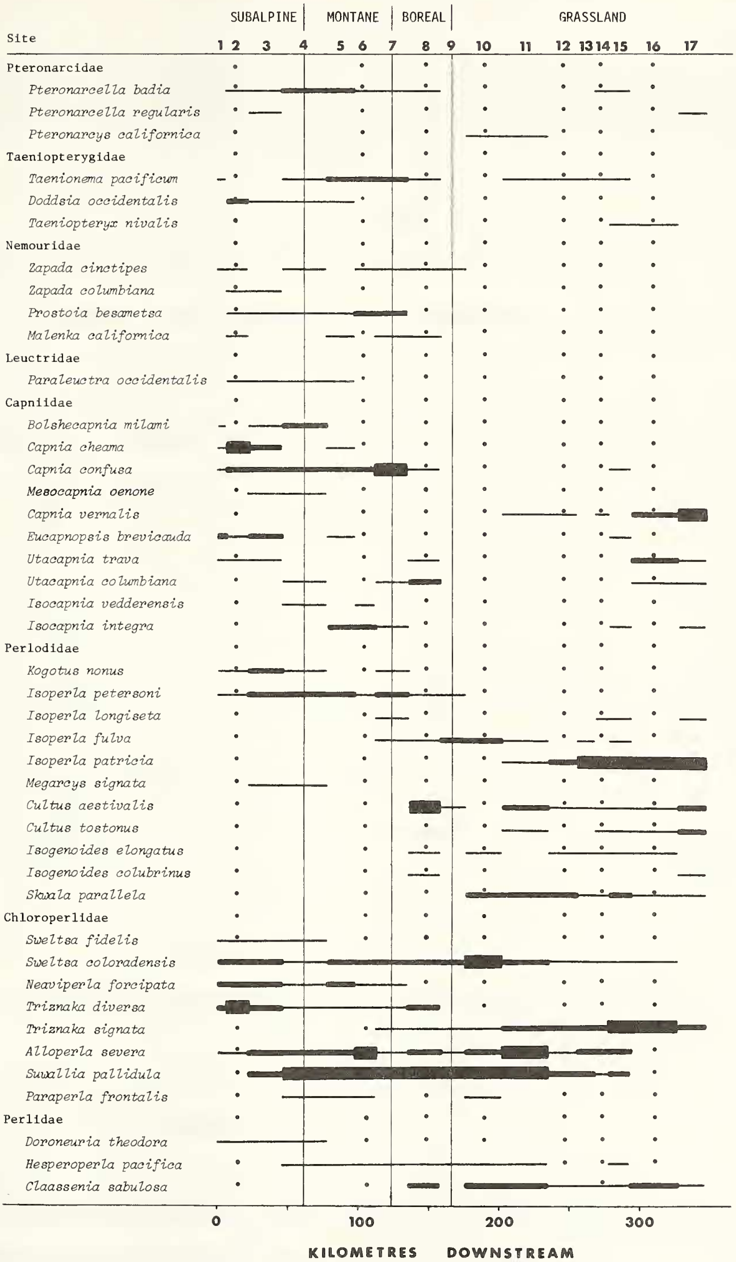

Figure 4. Distribution of 43 species of Plecoptera from Bow River. Abundance of each species is indicated by thickness of horizontal line. The thinnest line represents one to ten specimens collected, and thickest line represents 50 or more specimens. Nomenclature follows Baumann (1977).

TABLE I

PERCENT COMPOSITION BY SUBFAMILY OF BENTHIC[1] AND AERIAL PLECOPTERAN SAMPLES COLLECTED AT TWO SITES ON THE BOW RIVER

	Site 1		Site 2	
	Benthos	Aerial	Benthos	Aerial
Number of samples	15	11	15	11
Subfamily				
Nemourinae	16	6	18	4
Brachypterinae	+	1	6	4
Capniinae	11	31	6	26
Leuctrinae	-	2	-	1
Pteronarcinae	-	-	2	2
Isoperlinae	-	2	1	2
Perlodinae	6	1	25	3
Acroneuriinae	26	3	5	2
Chloroperlinae	41	54	37	58
Paraperlinae	-	-	+	
	100	100	100	100
Total number / m^2	289		1397	
Total number collected		140		303

[1] Data compiled from Robinson and Smith (1974)
+ present; - not collected

benthic or aerial sampling method. Only rare species were added to the list of adult taxa found at site 11 when the collecting effort was doubled at this site. These data suggest that bimonthly collections of adult stoneflies approximate the relative abundance of aquatic and aerial stages at any given site. Adult collections are more suitable than larval collections for determining distribution of stoneflies because all specimens can be identified to species.

Bray-Curtis ordination identified four plecopteran associations from the study area (Fig. 5). Upstream and downstream limits of some associations were near boundaries of vegetation zones found in the same area. Climatic factors that determined distinct vegetation zones also appeared to influence distribution of stonefly associations.

Plecopteran faunas in streams do not occur in discrete species groups. Typically, along the length of a river there is a progressive change in species with a broad overlap in distribution of many species (Knight and Gaufin, 1966, Donald and Anderson, 1977, and others). The majority of species in the study area were found in two or more associations. Only 13 of 43 common species were limited in their distribution to one of the associations (Fig. 4). However, Bray-Curtis ordination successfully identified those sites most similar to each other, and therefore ordination can be used to delineate parts of a stream that have a similar fauna or association.

In the following paragraphs, effects of hydroelectric dams and sewage effluents on species in the four associations (Fig. 5) are evaluated, beginning with the plecopteran fauna found in the subalpine and montane vegetation zone.

In the subalpine-montane zones (sites 1-7), there were changes in number of species and overall abundance of Plecoptera at certain sites (Fig. 4). Increase in abundance of Plecoptera downstream from Lake Louise and Banff was probably related to at least two factors: increase in discharge and width of Bow River at these sites (2 and 5), and to stream fertilization from organic sewage. An increase in the standing crop of benthos is typical of mild organic pollution (Hynes 1960). Sewage from the towns did not affect the overall distribution of plecopteran species with the possible exceptions of *Utacapnia columbiana* (Claassen) and *Kogotus nonus* (Needham and Claassen) (Fig. 4).

There was a major discontinuity in distribution of the stonefly fauna in the boreal vegetation zone. Seventeen species had either upstream or downstream distribution limits in or near this vegetation zone. A similar situation occurred in the near pristine Waterton River drainage where 58% of the common species had either upstream or downstream limits at 1235 m (± 100 m), the lower boundary of the montane zone (Donald and Anderson, 1977). These data suggest that discontinuity in species distribution near the downstream limit of the montane belt on the Bow River was due to natural changes in the lotic environment, and was not necessarily due to effects of sewage and hydroelectric dams in this area.

In the boreal zone there was a sharp drop in both diversity and abundance of stonefly species below the central hydroelectric dam (site 9, Fig. 3), followed by a gradual increase. It is well known that for the first few kilometres below large dams species diversity and overall abundance of stonefly larvae are reduced (Gore 1977, Radford and Hartland-Rowe 1971, Spence and Hynes 1971, Trotsky and Gregory 1974, Ward 1976). Data presented by Gore(1977) for a Montana river and by Ward (1976) for a Colorado river suggest that complete recovery of a plecopteran fauna occurs about 30-60 km below dams, although this recovery probably depends on many factors such as size of tributary streams, size of reservoir, daily variation in water release, and release of either epilimnetic or hypolimnetic water.

As indicated by reduced species diversity and abundance, site 9 was unfavourable for plecopterans. This site was 4.1 km below the hydroelectric dam with the greatest daily variation in discharge. Three other sites (8, 10 and 11) were located between 14.2 and 20.6 km below dams (Fig. 3). Dams have an unfavourable effect on plecopterans, and because three of the four dams in the study area were located in the boreal zone, it is possible that they were an important factor determining plecopteran faunal association identified from this section of the Bow River (sites 8-10, Fig. 5).

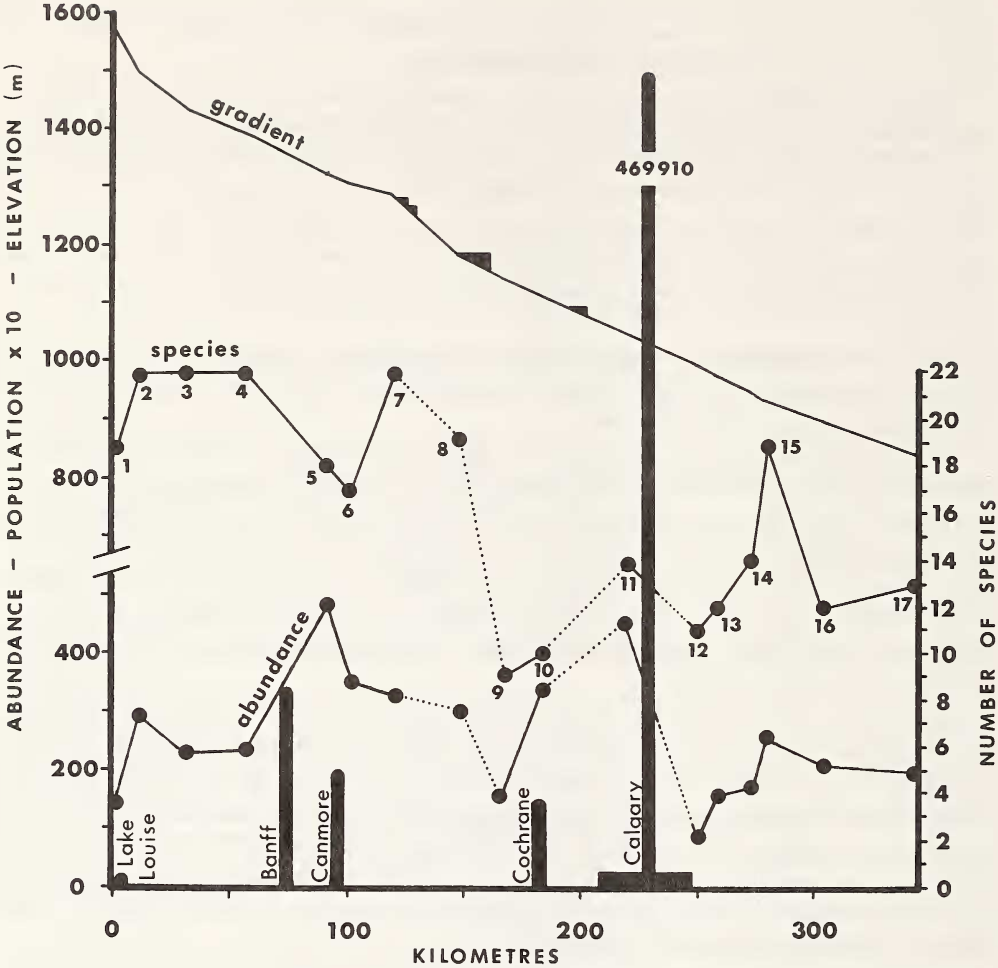

Figure 5. Scatter diagram of seventeen sites in the study area derived by Bray-Curtis polar ordination. Figure shows presence of four plecopteran faunal associations in the study area.

In other rivers in western North America, larvae of *Capnia vernalis* Newport and *Isogenoides colubrinus* (Hagen), (Gore 1977), *Pteronarcys californica* Newport (Elder and Gaufin 1973 and Ward 1976),*Skwala parallela* (Frison), *Claassenia sabulosa* (Banks), *Pteronarcella badia* (Hagen), and *Triznaka signata* (Banks) (Ward 1976) are absent from, or reduced in numbers below dams. Similar results were found for adults of these same species along the Bow River (Fig. 4).

In the grassland vegetation zone reduction in the plecopteran fauna occurred immediately downstream from Calgary (site 12). This part of the river received organic wastes as well as some thermal and toxic pollutants from Calgary. Deterioration in water quality in this area was indicated by a large increase in abundance of total coliform bacteria (Fig. 2). Many capniids, perlids, and pteronarcids were either reduced in abundance or were absent from this zone. Species completely eliminated from at least 26 km of river downstream from Calgary (sites

12-14) were *Pteronarcys californica* Newport, *Capnia confusa* Claassen, *Eucapnopsis brevicauda* (Claassen), *Utacapnia trava* (Nebeker and Gaufin), *Utacapnia columbiana* (Claassen), *Isocapnia integra* Hanson, and *Hesperoperla pacifica* (Banks). Four other species [*Skwala parallela* (Frison), *Isoperla patricia* Frison, *Suwallia pallidula* (Banks), *Triznaka signata* (Banks)] appeared to be tolerant of some organic pollution as indicated by their abundance two kilometres downstream from Calgary.

In general, stoneflies are intolerant of severe organic pollution and are usually eliminated by it (Gaufin 1958, Gaufin 1962, Gaufin 1973, Hynes 1960, Paterson and Nursall 1975). Stoneflies probably did not occur immediately below the city sewage outfalls. The relatively high stream gradient and high levels of dissolved oxygen in the Bow River contributed to a rapid recovery of water quality that permitted a few species to exist two kilometres downstream from Calgary.

Downstream from the last sewage outfall from sites 12 to 15 there was a progressive increase in the species diversity and abundance of Plecoptera (Fig. 3). This part of the Bow River was in a recovery zone where many species that were intolerant of the upstream effects of severe pollution once again reappear. Although the distributions of some species have not been greatly reduced (e.g. the perlid *Hesperoperla pacifica),* at least two capniid species (*Utacapnia columbiana* and *Isocapnia integra* have probably been eliminated by dams and sewage from more than 150 km of river (Fig. 4).

The sharp drop in species diversity, but not in abundance of stoneflies, at sites 16 and 17 in the grassland belt was probably due to natural conditions in the lotic environment that were unfavourable for some species of Plecoptera. Reduced gradient (Fig. 3) and high summer temperatures could be responsible. In the Waterton River drainage, distributions of *Capnia confusa* , *Eucapnopsis brevicauda* , *Taenionema pacificum* (Banks), and *Hesperoperla pacifica* did not extend far into the grassland zone (Donald and Anderson, 1977). These four species had a similar distribution in the Bow River. At least six other species represented at site 15, but not at Sites 16 and 17, have not been collected from rivers in south-central Alberta (Ricker 1943 and unpublished distribution records). These data suggest that change in the plecopteran fauna at sites 16 and 17 was due to natural changes in the lotic environment. The species represented at these two sites were identified as a second grassland association of Plecoptera (Fig. 5).

In this study, collections of adult Plecoptera were used to document patterns in distribution of stonefly species in the Bow River. Distribution of these species was influenced by hydroelectric dams, domestic and industrial sewage and by natural environmental factors (probably climate, river gradient, etc.). It follows, that in regions with a diversity of plecopteran species, the distribution patterns of adult Plecoptera can be used as an indicator of effects of severe organic pollution and hydroelectric dams on the lotic environment.

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